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Flow Characteristics of a Porous Pipe Irrigation Lateral

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ABSTRAK

Paip poros adalah berguna untuk sistem pengairan mikro sama ada di permukaan atau subpermukaan tanah. Tetapi maklumat mengenai keseragaman luahan dan ciri pengendaliannya amatlah kurang. Makalah ini membentangkan kajian di UPM berkaitan hidraul paip poros untuk mencari hubungan tekanan atau turus dengan luahan dan kehilangan turus oleh geseran. Beberapa potong sampel paip poros yang diimport telah dikaji dengan meneliti respon luahan kepada beberapa turus tekanan dan kadaralir di hulu aliran. Luahan dari paip poros amat peka kepada perubahan tekanan dengan julat eksponen luahan 1.07 hingga 1.67. Beberapa carta telah dibuat bagi memudahkan rekabentuk paip poros untuk pelbagai aplikasi.

ABSTRACT

Porous pipe is useful for both surface and subsurface microirrigation systems. However very little information is available about its discharge uniformity and operating characteristics. This paper presents work done at UPM on the hydraulics of porous pipe to determine such performance criteria as the pressure-discharge relationship and friction head loss. Several lengths of imported porous pipe were subjected to various upstream pressure inputs to determine the average discharge along the lateral and the associated pressure losses. The flow in the emitter lateral was found to be highly sensitive to pressure with discharge exponent ranging from 1.07 to 1.67. Graphs were developed to facilitate design of porous pipe laterals for various applications.

Keywords: microirrigation, hydraulics, porous pipe, discharge exponent, friction head loss, friction factor

INTRODUCTION

Porous pipe is a product from extruded membrane manufactured from recycled tyres and virgin polyethylene or a resin treated textile product. There is little direct control over the size and distribution of the pores. However, since it gives regular exudation, irrigation is localized in a wetted strip whether it is buried or laid on the ground surface (Yoder and Mote 1995). It is being widely marketed for surface and subsurface microirrigation. However very little information is available about its discharge uniformity and operating characteristics.

Porous pipe may be suitable for several installations such as on the surface, under plastic, buried, in straight lines, winding, following specific shapes, and vectors for trees or potted plants, whether in greenhouses, flower beds with lawns, trees, plant nurseries and orchards or other plantations. The investment cost for porous pipe may be high compared to other irrigation systems. However the advantages, as claimed by the manufacturers, such as an increased water use efficiency, a continuous wetted strip, and less weed growth due to dry soil surface for subsurface application are good reasons why subsurface porous pipe irrigation is worth considering.

One porous pipe manufacturer claims that their porous pipe or "CT12-poritex exudating hose" is a special and unique type of microirrigation component manufactured from woven plastic which acts as a conduit and emitter. They claim that any debris trapped in the hose can be easily flushed by simply removing the end plug. Thus this property makes poritex suitable for using dirty irrigation water. They also claim that the porous pipe can last for 8 years with minimal sign of deterioration after more than 5 years in the field (Creaciones Tecnicas 1995). The normal operating pressure is 20– 80 kPa or 2-8 metres of water column.

Burt and Styles (1994) reported work on porous pipe in which the thick wall is porous and water "weeps" out along the complete length. These pipes have extremely large variations in discharge per metre of pipe, a discharge exponent of more than 1.0, and appear to be highly susceptible to plugging. Also the small internal diameter of the pipe they tested contributed to high friction losses. Given those attributes, distribution uniformity (DU) achieved would probably be very low. Yoder and Mote (1995) found manufacturing coefficient of variation of 9–15% even for a 6-m length of a certain type of porous pipe. In the field, a uniform water distribution from a long lateral with a low pressure head loss is desired.

SPATIAL VARIATION OF OUTFLOWS

Discharge variation along a lateral pipe occurs due to pressure variation caused by pipe friction and elevation difference, and emitter variation caused by manufacturing, clogging and ageing. Ignoring the variation in porosity due to manufacturing variability and considering only the hydraulic effects, the variation in outflows can be predicted from a knowledge of the variation in pressures along the lateral. This can be determined for any combination of pipe length and mean discharge, from the known inlet pressure and pressure loss. This knowledge is required in order to determine the maximum lengths of porous pipe laterals that would give acceptable performance.

Emitter discharge exponent can range from 0.0 for a completely pressure compensated emitter, 0.5 for turbulent flow emitters and 1.0 for laminar flow emitters. A typical design criteria is to limit the variation in outflows within 10% of the mean discharge. For turbulent flow emitters, this corresponds to 20% pressure variation. However for laminar flow emitters, a 10% discharge variation corresponds to 10% pressure variation. This shows that the higher the discharge exponent the smaller is the pressure range allowable to give an acceptable irrigation uniformity.

MATERIALS AND METHODS

A test facility for hydraulic studies of porous pipe was fabricated at the Irrigation and Drainage Laboratory of the Department of Biological and Agricultural Engineering, UPM. The experimental set-up consisted of a water source, an electric pump, a flow meter, pressure gauges, control valves and volume measuring cylinders. The set-up can measure water pressures of up to 250 kPa and flow rates of up to 1000 litres per hour. Several lengths of imported "poritex" porous pipe were subjected to various flow rates and inlet pressures to determine the average discharge along the lateral and the frictional head loss. The porous pipe, 0.5 mm thick and 12 mm in diameter, was cut into sample lengths of 45, 65, 80,100, 130, 150 and 195 m. All hydraulic studies were done with the porous lateral pipe on level ground. Manufacturing variability was not tested in this study.

For a particular length of porous pipe and a selected inlet pressure head, the flow meter reading was recorded when the dial at the pressure gauge stabilized after starting the electric pump. Pressure loss in the pipe length was measured by a mercury manometer fixed at the distal end of the pipe length. The control valves were adjusted to obtain various upstream pressures and flow rates in the pipe. The water temperature at the water source was also recorded. Data obtained were analysed for average discharge rates, pressure head losses, upstream Reynolds number, and friction factor for various inlet pressures and flow rates in the test samples.

RESULTS AND DISCUSSION

Pressure-discharge Relationship

Analyses of pressure head and discharge data show that the porous pipe discharge can be related to pressure head with a power function. *Fig. 1* shows the H-Q curves for various pipe lengths in a linear scale. Presented in a log-log

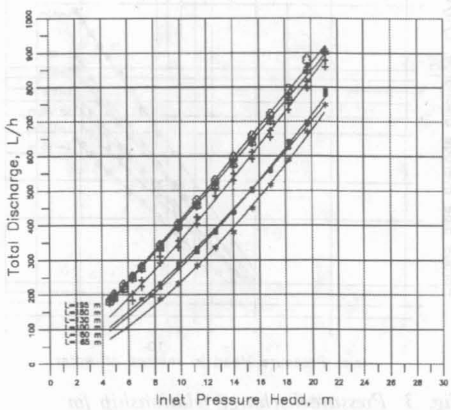

Fig. 1 Total flow rate versus inlet pressure head for various lengths of "poritex" porous pipe

scale as in *Fig 2*, the data points fall in straight lines for heads up to 21 m and total flow rates up to 900 l/h. The pipe flow was turbulent with upstream Reynolds number up to 35,000 tapering to laminar flow at the distal end of the pipe.

The pressure-discharge relationship for various lengths of the porous pipe is shown in *Fig. 3*. The data points were fitted to power functions in the form of $q=KH^x$ where q is the average discharge in l/h/m, H is pressure head in metres of water column, K is a constant of proportionality and x is the discharge exponent. The emitter flow was found to be highly sensitive to pressure with discharge exponent ranging from 1.07 to 1.67, as shown in Table 1.

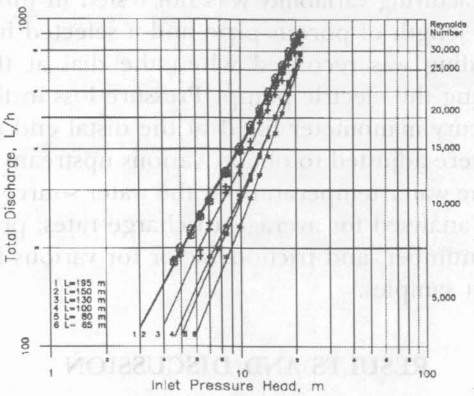

Fig. 2 A log-log plot of inlet pressure head versus total discharge and upstream Reynolds number.

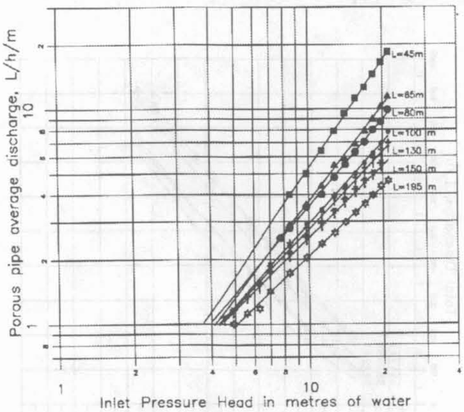

Fig. 3 Pressure-discharge relationship for "poritex" pipe. The slope is the discharge exponent x in $q = KH^x$

TABLE 1
Constant of proportionality and discharge exponents for various porous pipe lengths

Porous Pipe Length (m)	K	X
45	0.11	1.67
65	0.11	1.51
80	0.16	1.36
100	0.16	1.26
130	0.17	1.21
150	0.19	1.12
195	0.18	1.07

To simplify the use of the H-q curves, *Fig. 4* was developed to show the average discharge versus pipe length for various pressure heads. These curves make design work easier for landscaping, orchards or row crops because any length of the porous pipe with a certain inlet pressure head is easily determined for any average design discharge required. However for high irrigation uniformity, designers should be guided by the allowable head loss for the lateral.

Considering the spatial uniformity outflows along the length to be kept to ± 10% of the mean value, then (with the discharge exponent in the H-Q relationship in excess of 1.5 for short lengths of porous pipe) the pressure variation along the pipe must be limited to ± 7%. This is equivalent to limiting the head loss to about 14% of the inlet pressure. These criteria allow designers to specify upper limits of lengths and discharge above which the performance of a porous pipe lateral will be unacceptable.

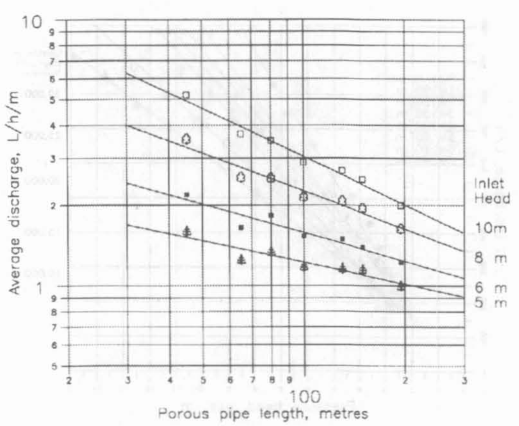

Fig. 4 Average discharge from a specified inlet head for any length of "poritex" porous pipe up to 200 m.

Pressure Head Loss in Porous Pipe

The head loss is a linear function of pipe length. This is well known and is an essential feature of all pipe flow equations such as Darcy-Weisbach or Hazen-Williams. *Fig. 5* shows the inlet head versus head loss for various lengths. Lower head loss occurs as a result of lower inlet heads irrespective of the lateral lengths. This means that the porous pipe is best used with low inlet pressure input.

Fig. 6 shows the frictional head loss versus the total discharge and upstream Reynolds number of the flow for various lengths of the porous pipe. Computing the flow regimes, turbulent flow (Re > 4000) occurred at total discharge above

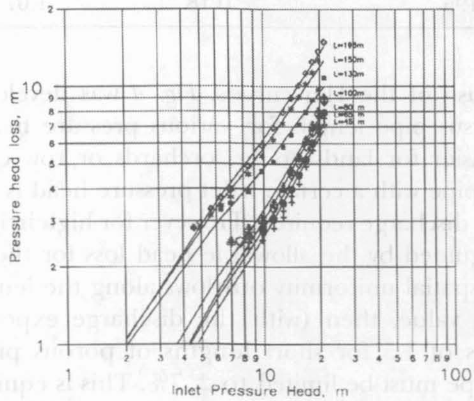

Fig. 5 Pressure head loss versus inlet pressure head for various porous pipe lengths

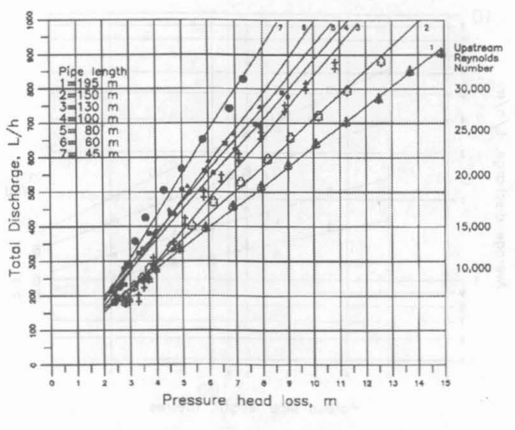

Fig. 6 Pressure head loss versus total discharge and upstream Reynolds number for various porous pipe lengths

110 l/h and laminar flow (Re < 2000) occurred at the distal end where flows were less than 55 l/h.

Fig. 7 shows the average discharge rate and the associated pressure head loss for various lengths of the porous pipe. *Fig. 8* was developed to ease design work in the determination of pipe length for any average design discharge with a certain operating inlet pressure head. The relevant equations for average discharges from 1–5 l/h/m are given in the graphs for any pipe length up to 200 m.

Fig 9 shows the pressure head loss versus pipe length for various inlet heads. It is obvious that the slope of the curve is gentler with lower inlet head

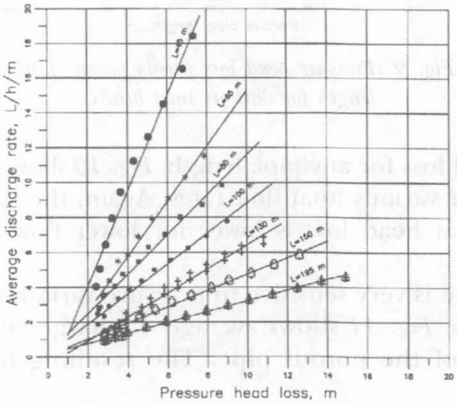

Fig. 7 Pressure head loss versus average discharge rate for various porous pipe lengths.

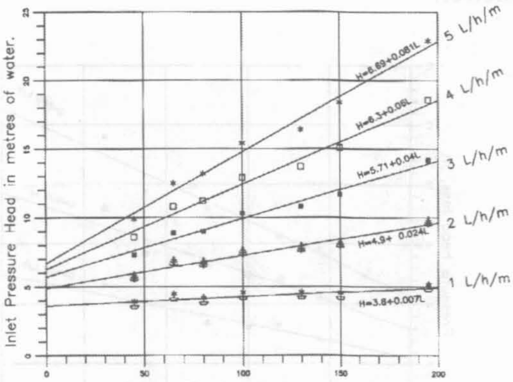

Fig. 8 Average discharge from a specified inlet pressure head for any length of "poritex" porous pipe up to 200 m.

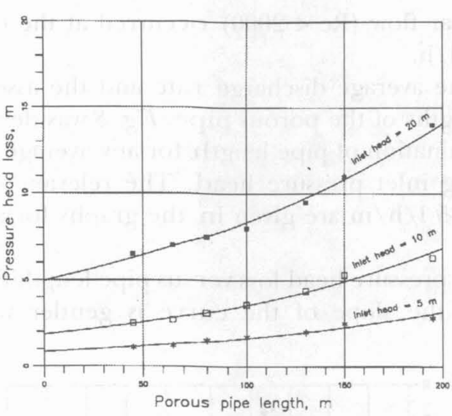

Fig. 9 Pressure head loss versus porous pipe length for various inlet heads

indicating lower head loss for any pipe length. *Fig. 10* shows pressure head loss versus pipe length for various total flow rates. Again, the slope of the curve is gentler indicating that head loss is lower for lower flow rates for any pipe length.

Since porous pipe is very sensitive to pressure variation, it is desirable to have low head losses. *Fig. 11* shows average discharge versus ratio of head loss to total length of the porous pipe. The resulting best fit equation is given by

$$q = 136\ (HF/L)^{1.173} \tag{1}$$

where q is average discharge in l/h/m, HF is frictional head loss and L is pipe length, both in metres.

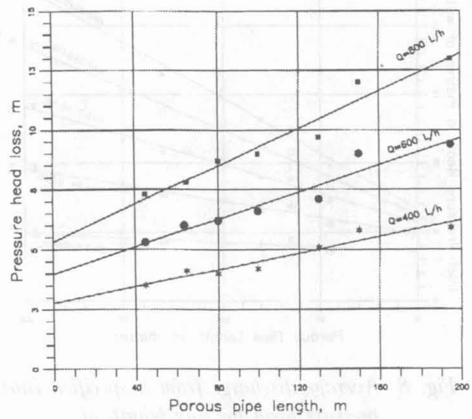

Fig. 10 Pressure head loss versus porous pipe lengths for various total flow rates

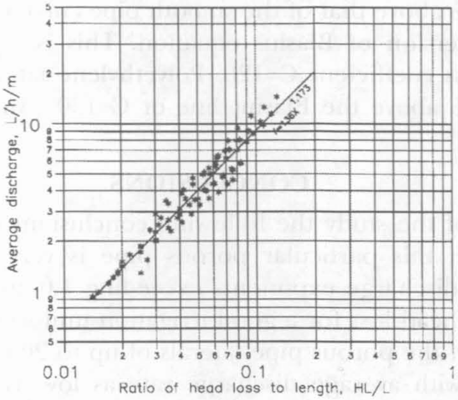

Fig. 11 Average discharge versus ratio of head loss to pipe length

Friction Factor-Reynolds Number Relationship

The Darcy-Weisbach head loss formula was used to determine the friction factor in the porous pipe. For a pipe with multiple outlets the equation is multipled by a factor for dividing flow. Since the porous pipe exudates water all along its length, it is assumed to have infinite outlets. Thus the factor is taken to be 0.33 (Massey 1984). This means that the head loss in a porous pipe is only one-third that of a similar size pipe of similar material carrying a uniform flow of the same magnitude. Spatially varied hydraulic theory compares the results of this work with equations developed for analysis of lateral pipe. This analysis allows prediction of the uniformity of outflows and extension of the results to laterals of different diameter.

Analysis of the frictional head loss shows that the porous pipe was not as smooth as an equivalent size polyethylene pipe. *Fig. 12* shows that the friction

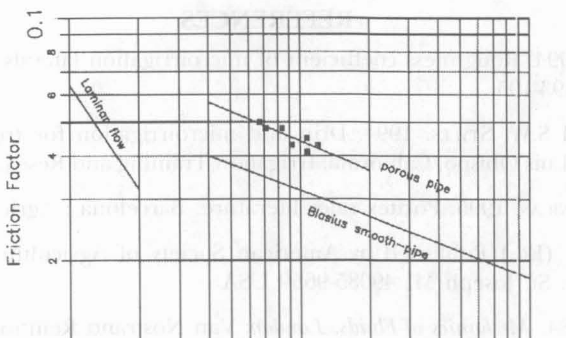

Fig. 12 Friction factor versus Reynolds number for flow in 12mm diameter "poritex" porous pipe

factor is about 40% above that of the smooth pipe curve of von Karman-Prandtl or its linearized version of Blasius equation. This is equivalent to a Hazen-Williams roughness coefficient C=120. Polyethylene lateral pipes usually have friction factor 10% above the Blasius line or C=130 (Amin 1994).

CONCLUSIONS

From the results of the study the following conclusions can be drawn:

1. The flow from this particular porous pipe is very sensitive to pressure variation with discharge exponents exceeding 1.0 and as high as 1.6.
2. The allowable head loss for a good irrigation uniformity is very low. Hence long lengths of the porous pipe laterals of up to 200 m on a level field are possible only with average discharge rate as low as 1 l/h/m at an inlet pressure head of 5 m.
3. Graphs of *Figs. 4* and *8* may be used in the design of porous pipe microirrigation laterals. Eqn. 1 may be used for other estimates of average discharge.
4. The friction factor of this particular porous pipe material is about 40% higher than that of the smooth pipe described by the von Karman-Prandtl curve or the Blasius Equation for turbulent flow. This is equivalent to Hazen-Williams roughness coefficient of C=120.

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